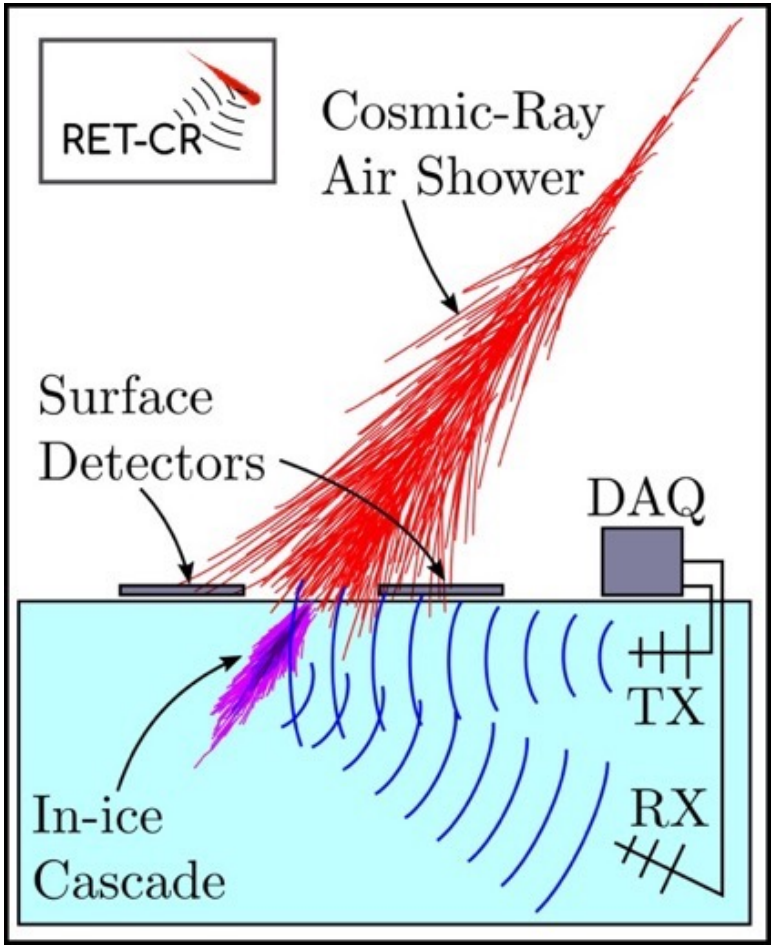
Deployment and Status Update of the Radar Echo Telescope

Dylan Frikken on behalf of the Radar Echo Telescope collaboration

Outline

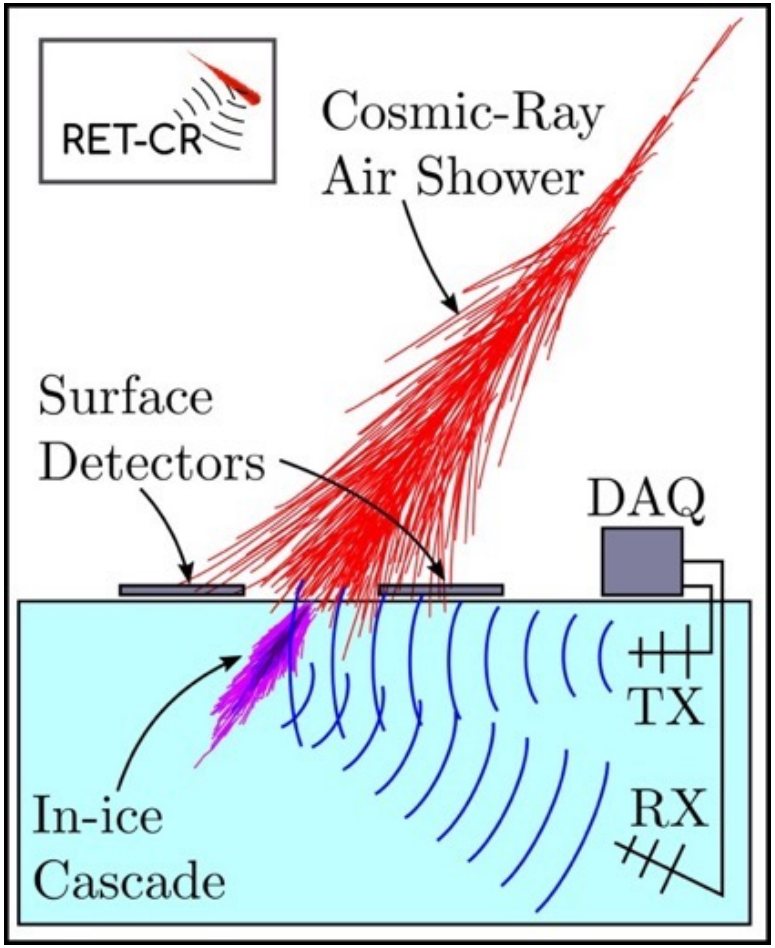
- Radar Echo Telescope for Cosmic Rays (RET-CR)
  - Big picture
  - Detector geometry
  - Deployment
  - Initial performance



RADAR ECHO TELESCOPE

What is the Radar Echo Telescope for Cosmic Rays?

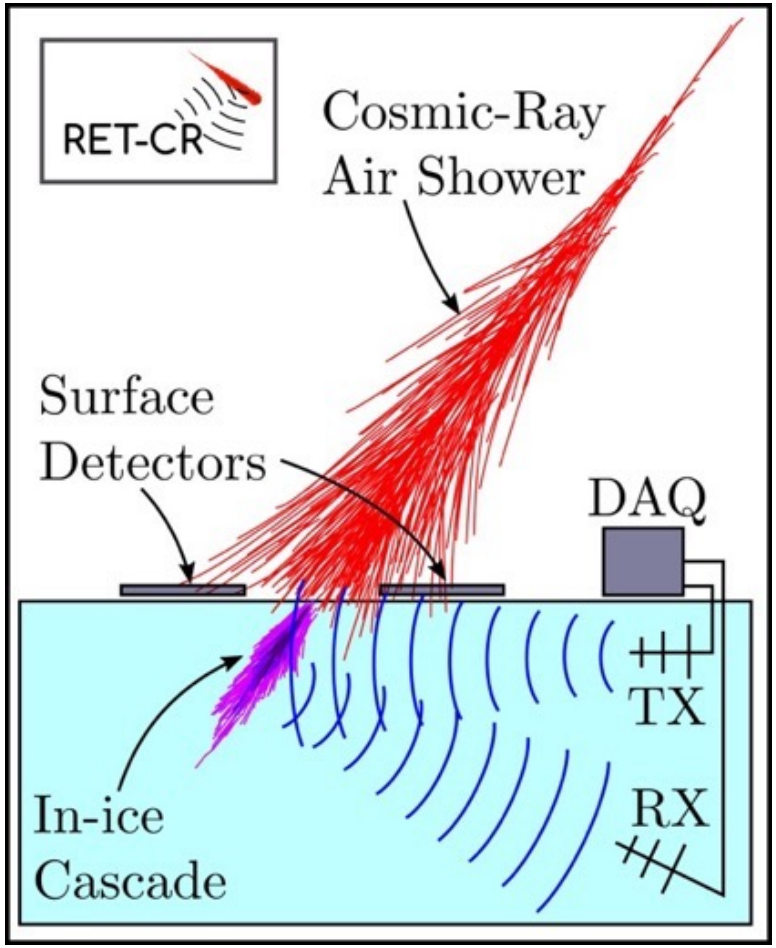
- Big picture:
  - Detect the ionization trail from a in-ice cosmic ray shower via active radar sounding
  - Use in-ice cosmic ray showers as an in-nature test beam to test the radar echo method for a future neutrino detector (RET-N)
  - The UHE cosmic ray interaction rate is orders of magnitude higher than for UHE neutrinos



RADAR ECHO TELESCOPE

What is the Radar Echo Telescope for Cosmic Rays?

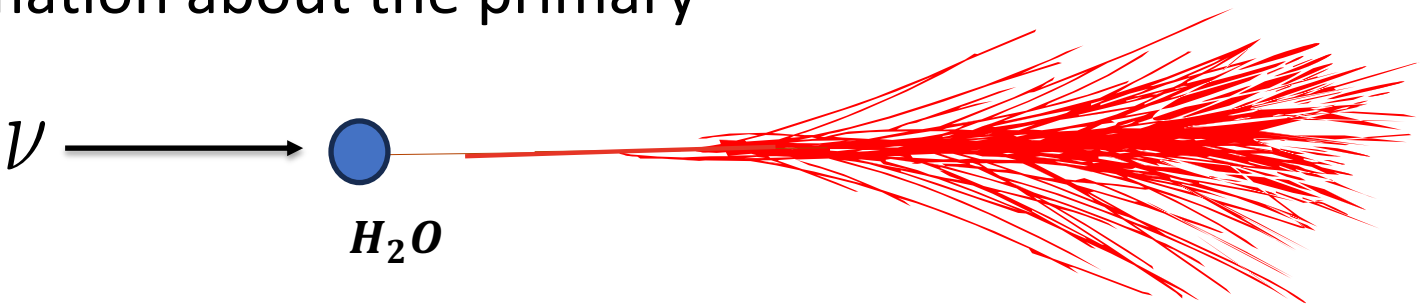
- Principle of operation:
  - Surface detectors (scintillator panels) detect charged particles in the cosmic ray air shower
  - These scintillator panels trigger the system to take a snapshot of the in-ice radar system, and an above surface radio antenna array



RADAR ECHO TELESCOPE

Ionization Trail

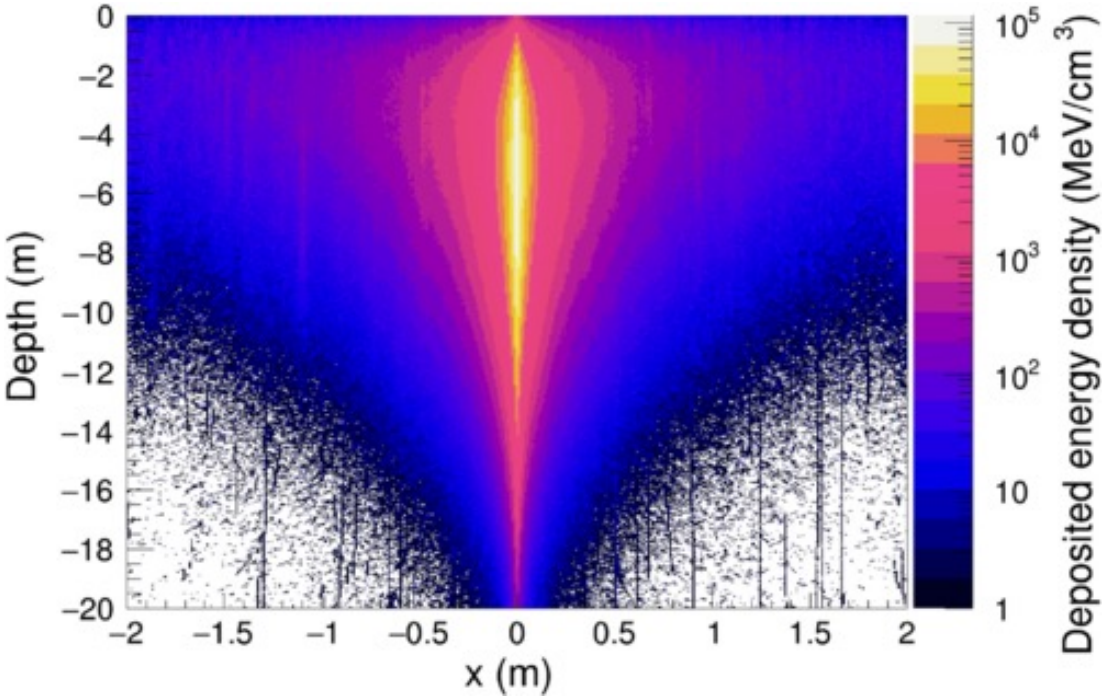
- High-energy particle interactions create a cascade of relativistic particles
  - These cascade particles lose energy to ionization leaving behind a short-lived blob of charge, called the Ionization Trail
    - The length of time this trail persists (the Free Electron Lifetime) depends on the material properties for free electrons
  - The length and direction of this Ionization trail can tell us information about the primary



In-Ice Cosmic Rays

- At high elevation, the in-ice cascade contains a significant fraction of the total cosmic ray shower energy

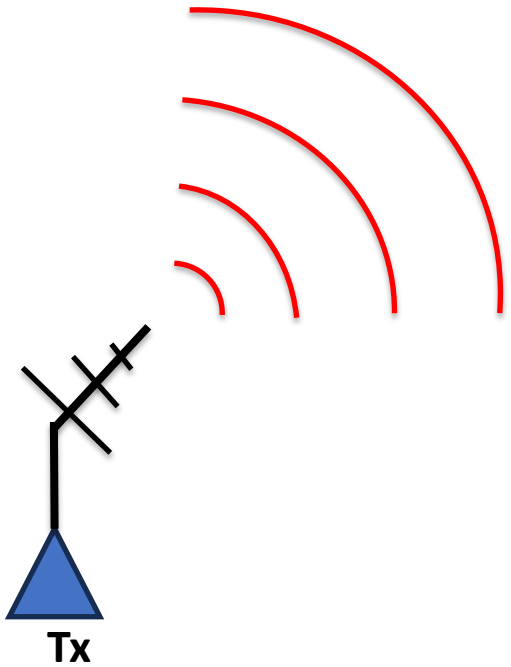
- There is a relative abundance of high-energy cosmic rays compared to UHE neutrinos (~1/day for cosmic rays, ~1/decade for UHE neutrinos)



https://doi.org/10.1103/PhysRevD.106.043023

Radar

- Basic concept:
  - A transmitter (Tx) broadcasts radio waves into a volume

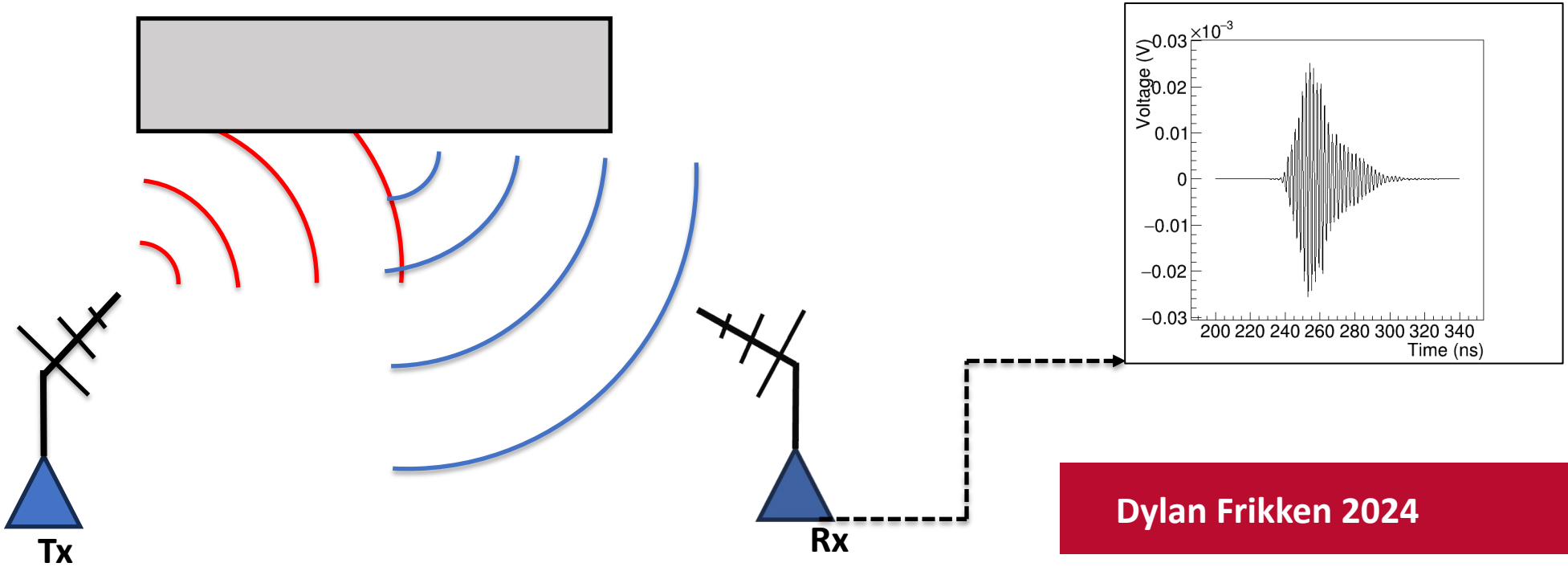


Radar

- Basic concept:
  - A transmitter (Tx) broadcasts radio waves into a volume
  - Receiver(s) (Rx) monitor that volume

Radar

- Basic concept:
  - A transmitter (Tx) broadcasts radio waves into a volume
  - Receiver(s) (Rx) monitor that volume
  - If some object that reflects radio is present in the volume, the transmitted signal will reflect into the receiver



RET-CR 2023 Season

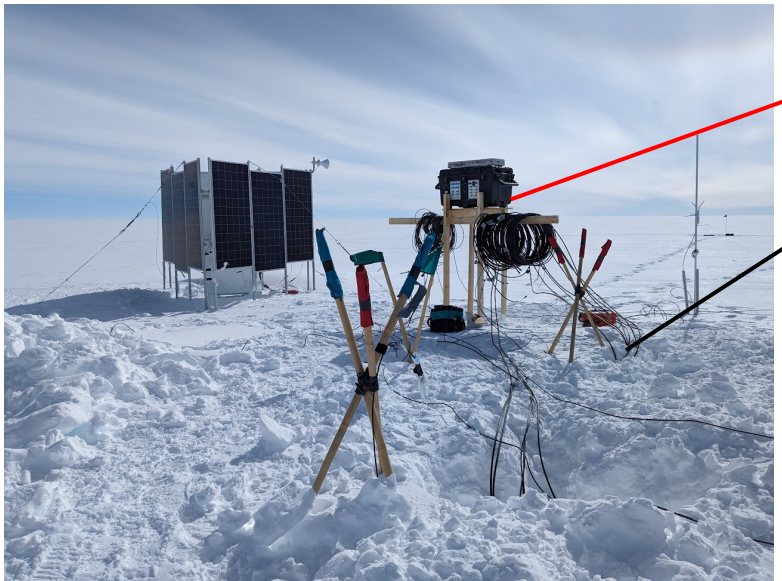
- RET-CR was first deployed in May 2023
- The instrument failed after ~5 weeks of operation, of which 9 days were quality data
- Improvements were made for the 2024 campaign

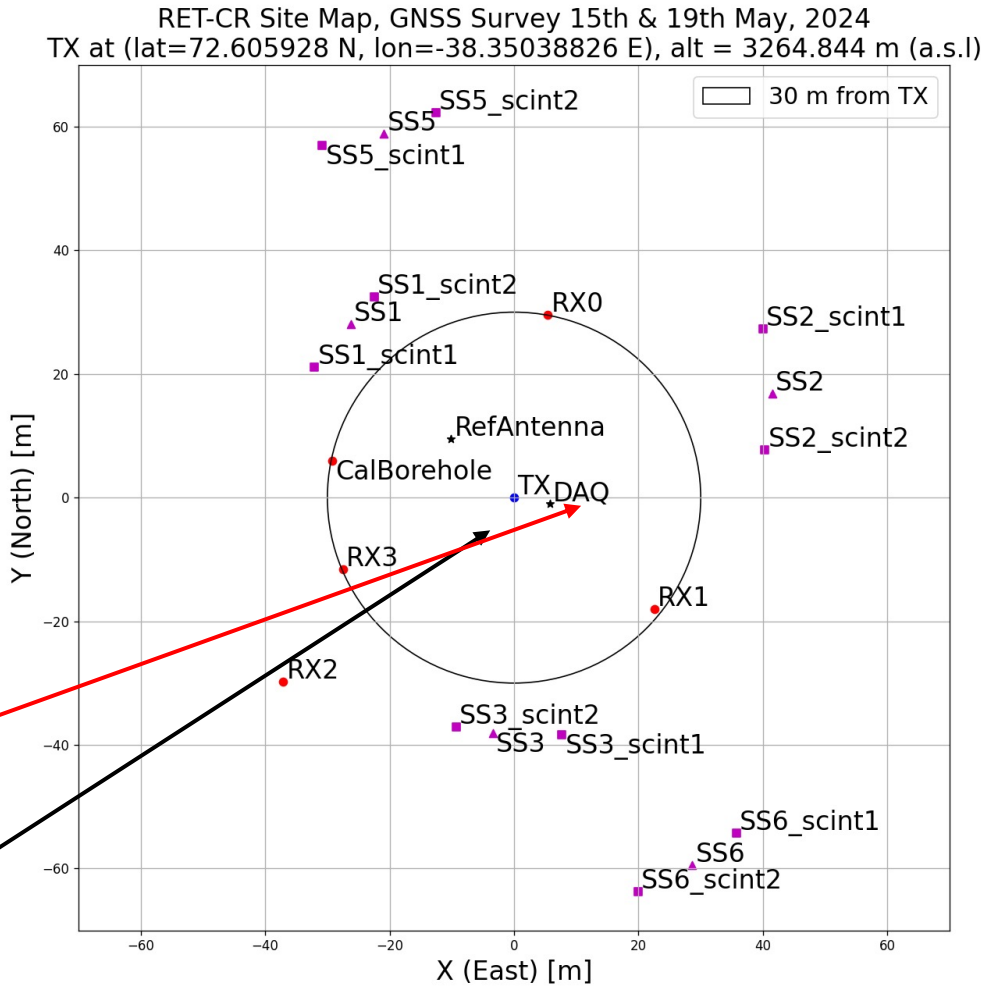
RET-CR 2024 Season Improvements

- New thermal management system
  - DAQ crate is now above surface
  - Heatsink cools the Tx amplifiers
- New scintillator timing system
- New surface station electronics
- Two additional surface stations (far baseline outriggers)
- One additional receiver
- Various on-site ice property measurements taken

RET-CR Layout

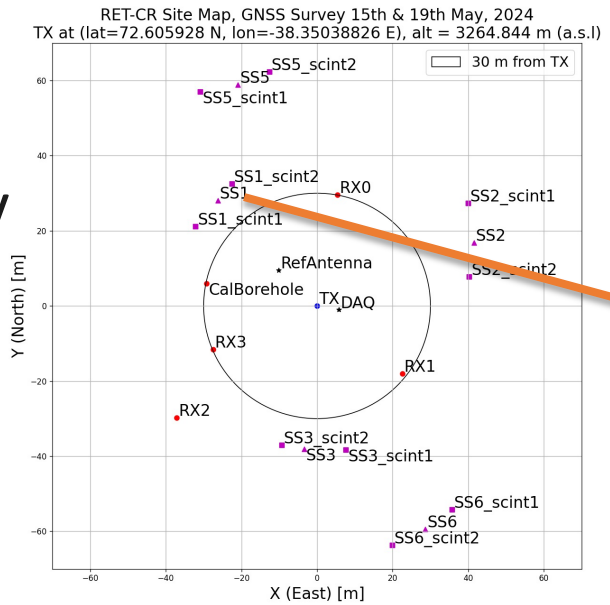
- Phased-Array Transmitter (Tx)
- Tx at center of geometry
- Tx broadcasting 180 MHz continuous sinewave (CW)
- Four receivers (Rx)
- Five surface stations

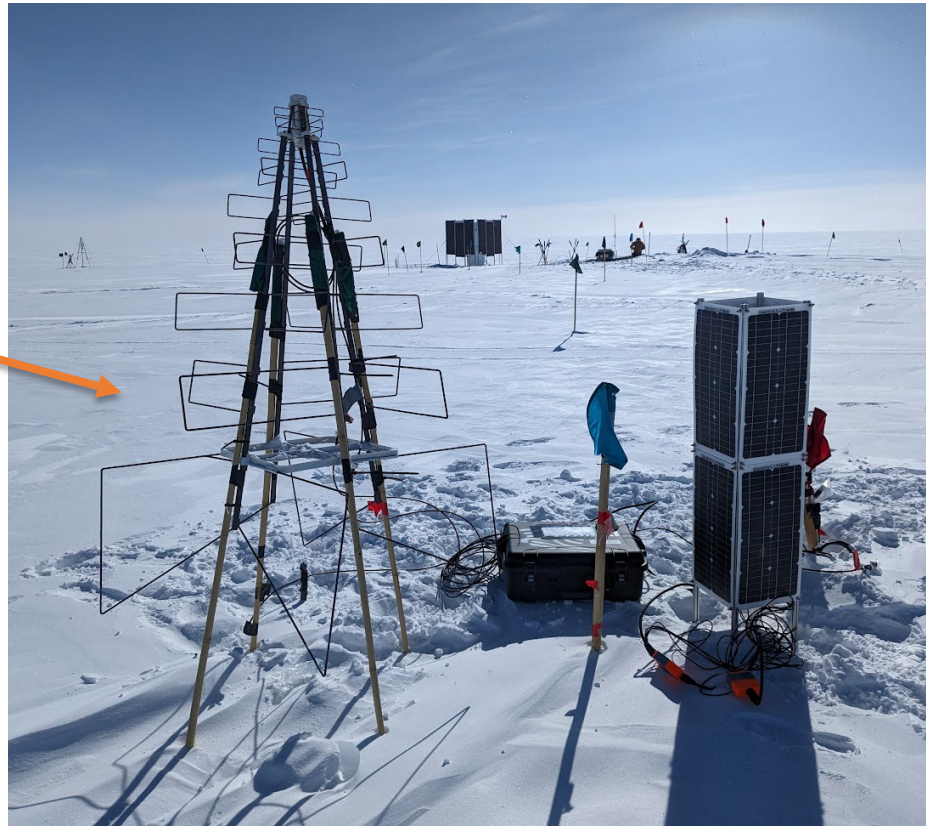




RET-CR Surface Stations

- Five independent surface stations
- Two scintillator panels separated by 20 m
- One log-periodic dipole antenna
- The scintillator panels coincidence is sent to central station which forms low level trigger

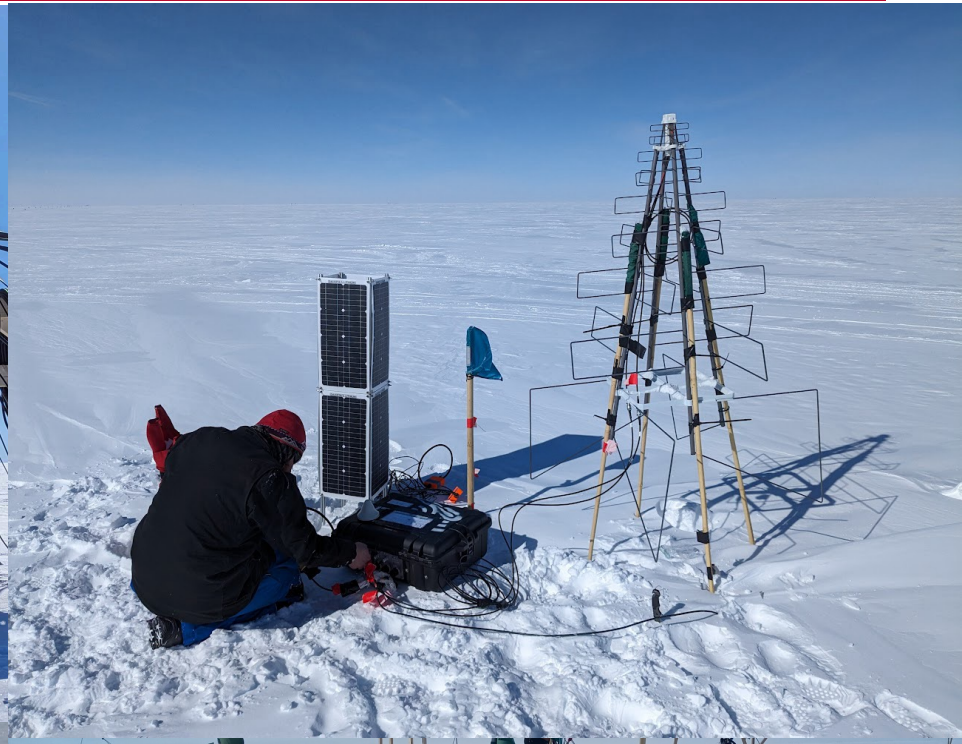




RET-CR 2024 Deployment

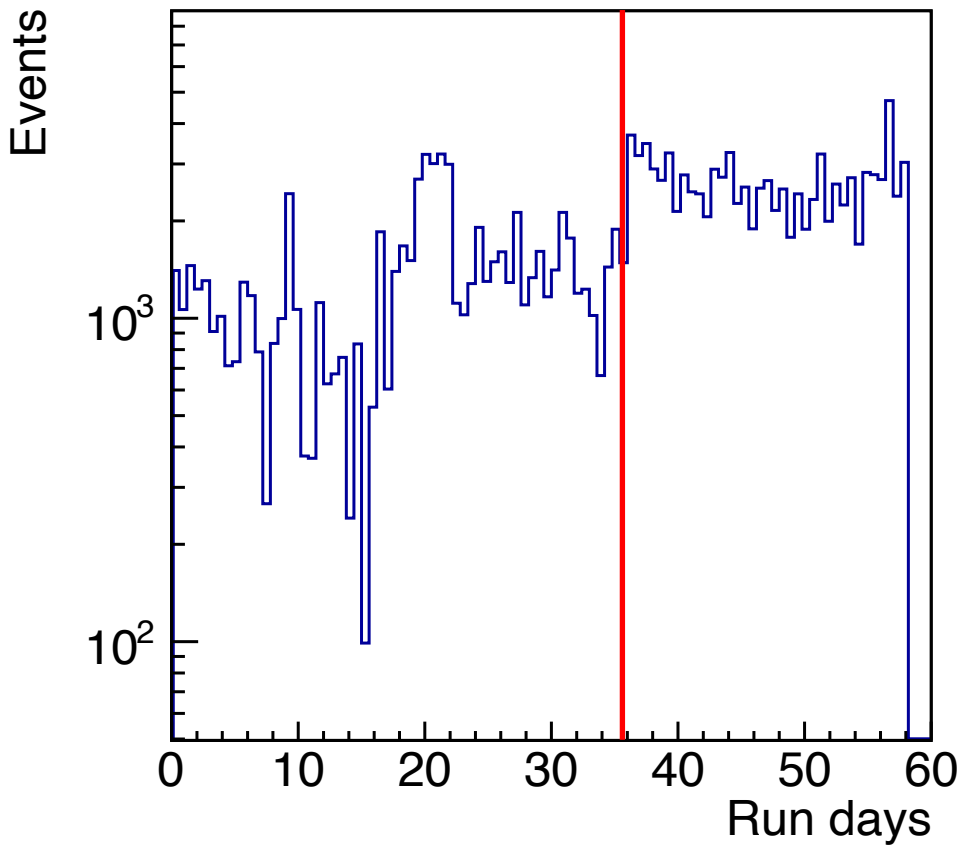
- May 2024 Deployment team:
  - Advanced Team (1 May – 22 May)
    - Steven Prohira – University of Kansas
    - Simon De Kockere - Vrije Universiteit Brussel
    - Dylan Frikken – Ohio State University
  - Late Team (9 May – 22 May)
    - Alex Kyriacou – University of Kansas
    - Curtis McLennan – University of Kansas

RET-CR Deployment



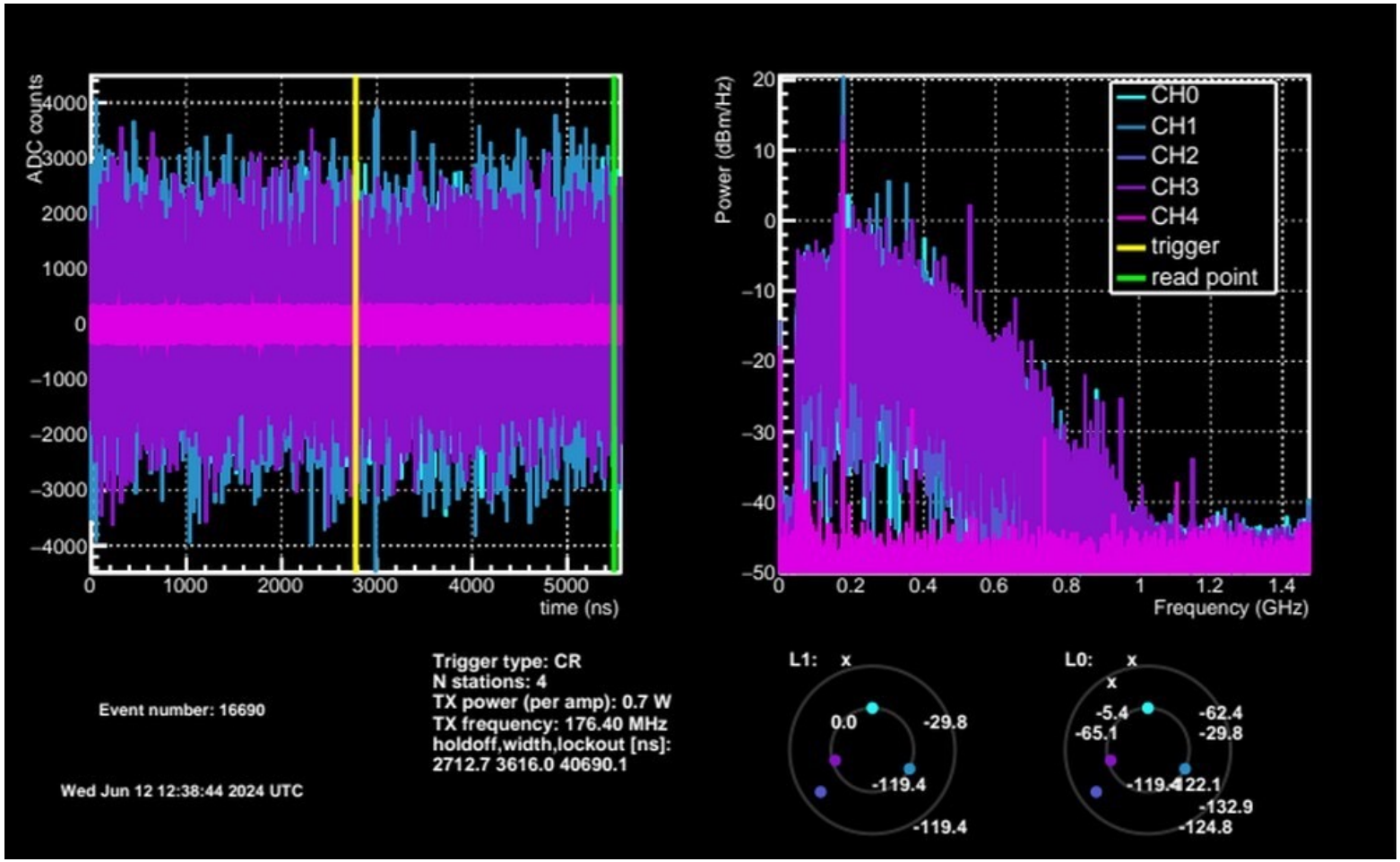
RET-CR Initial Performance

- Here we show the cosmic ray triggered events over the 2024 campaign
- This sample consists of all cosmic ray events which satisfied the surface station array requirements
- Most of this sample is cosmic rays with energy below the threshold for a radar echo measurement



A new triggering scheme was developed during the campaign, producing a flatter event rate (denoted with red line).

RET-CR Initial Performance



This event viewer shows the waveform (left), frequency (upper-right), event geometry (lower-right) and event details of a cosmic ray triggered event

Tx power was increased to 5-10W per channel in mid-June

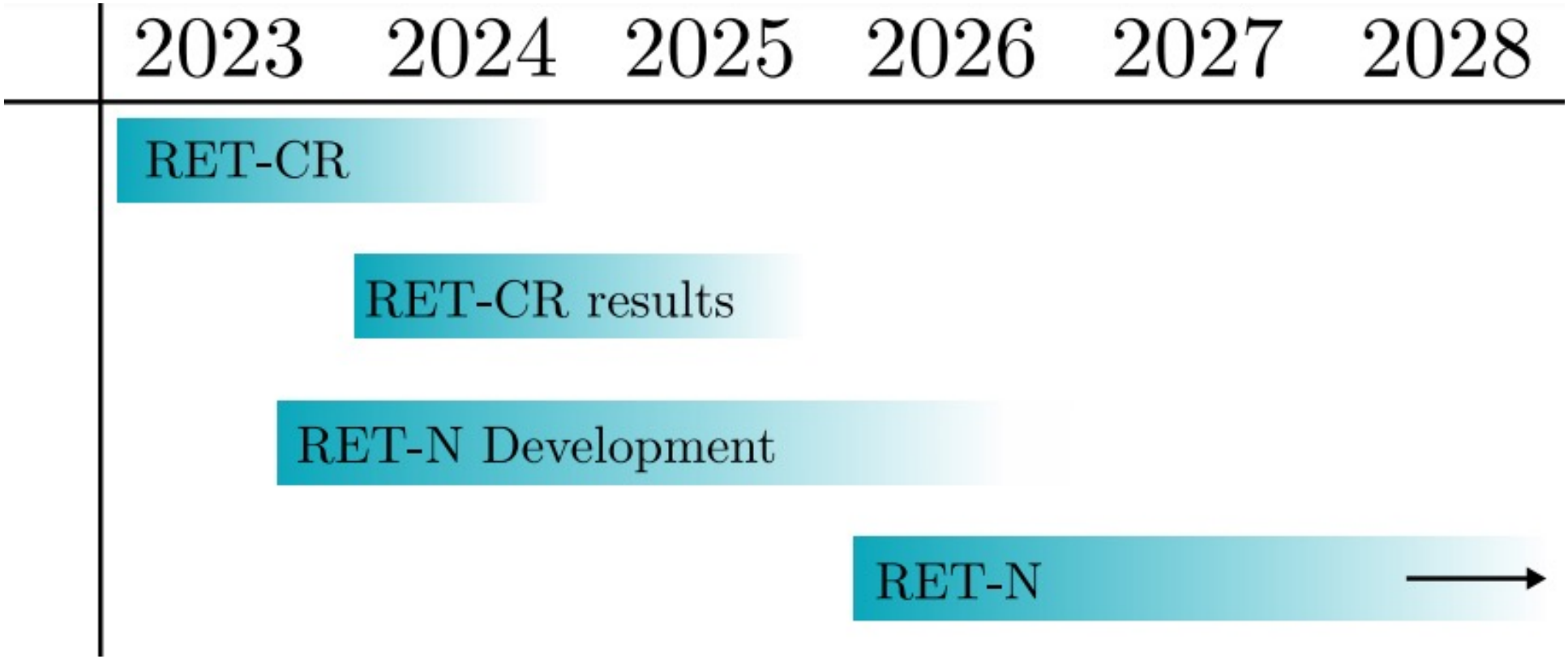
RET-CR Retro Team

- Steven Prohira – University of Kansas
- Krijn De Vries - Vrije Universiteit Brussel
- Katie Mulrey - Radboud University

Acknowledgements

- We would like to acknowledge the following people/groups
  - The CODALEMA collaboration for providing the surface radio DAQs used for RET-CR
  - The IceCube collaboration for providing the scintillator panels
  - The Summit Station staff for providing us cargo logistics, food, warmth, and fun!

Future Timeline



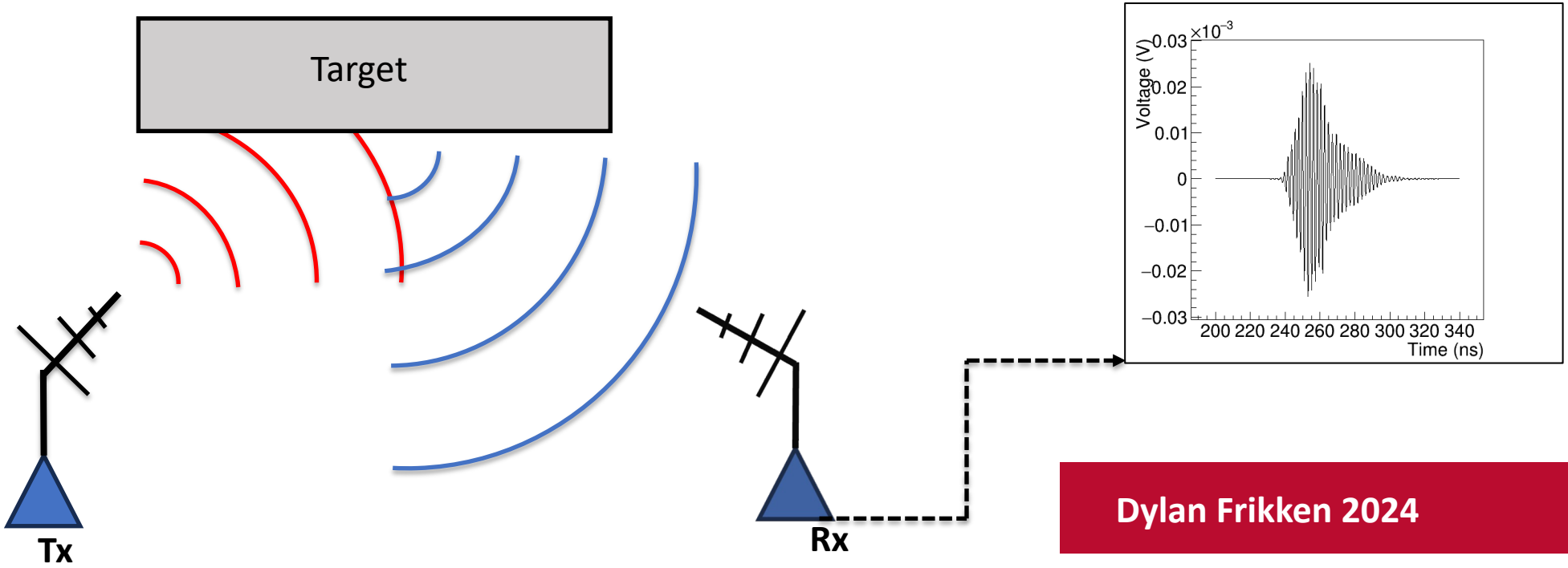
Thank you!

- RET Collaboration
  - The Ohio State University
  - IIHE/Vrije Universiteit Brussel & Université Libre de Bruxelles
  - University of Kansas
  - Penn State University
  - UW Madison
  - National Taiwan University
  - SLAC National Accelerator Laboratory
  - University of Chicago
  - Radboud University

Backup

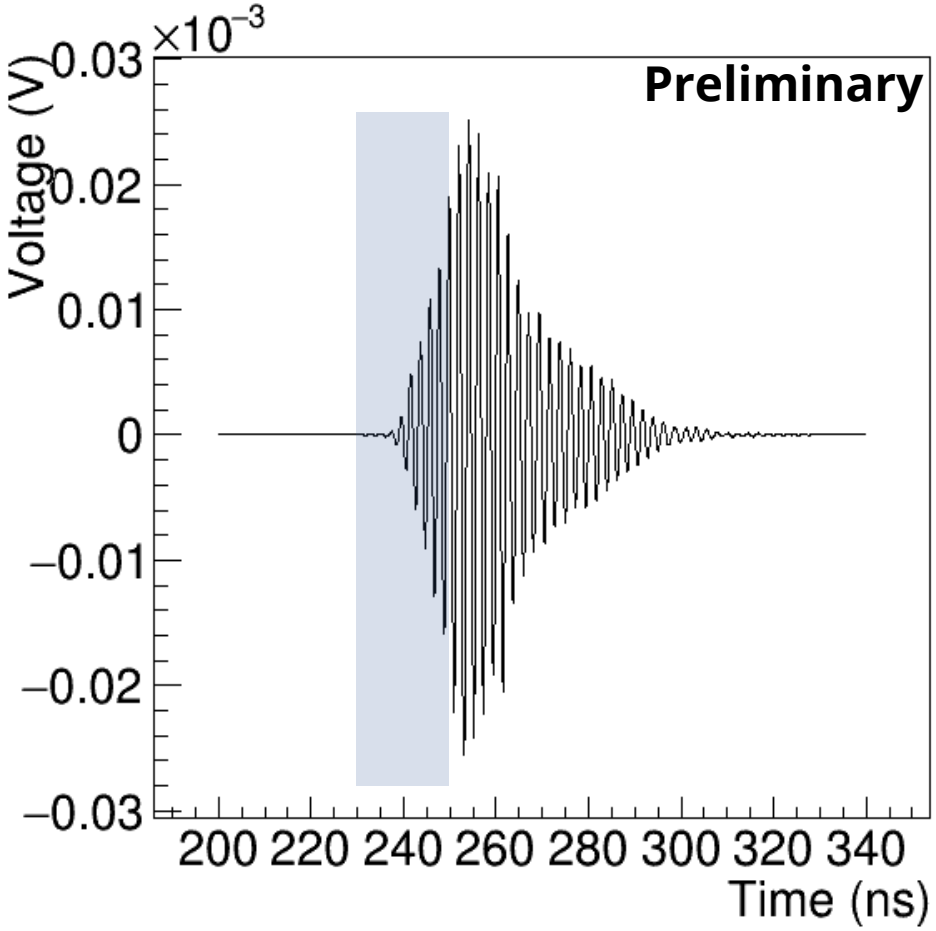
Radar

- Radar Cross Section
  - How ”detectable” is the target using radar?
  - Dictates the amount of power of the reflected (blue) waves
  - Ignores transmitted signal properties, media effects, and baseline distance
  - Goal of stealth plane design is to minimize this value



Investigation of Received Signal Properties

- RET simulated using RadioScatter (in-house radar reflection simulation with GEANT4) arXiv:1710.02883

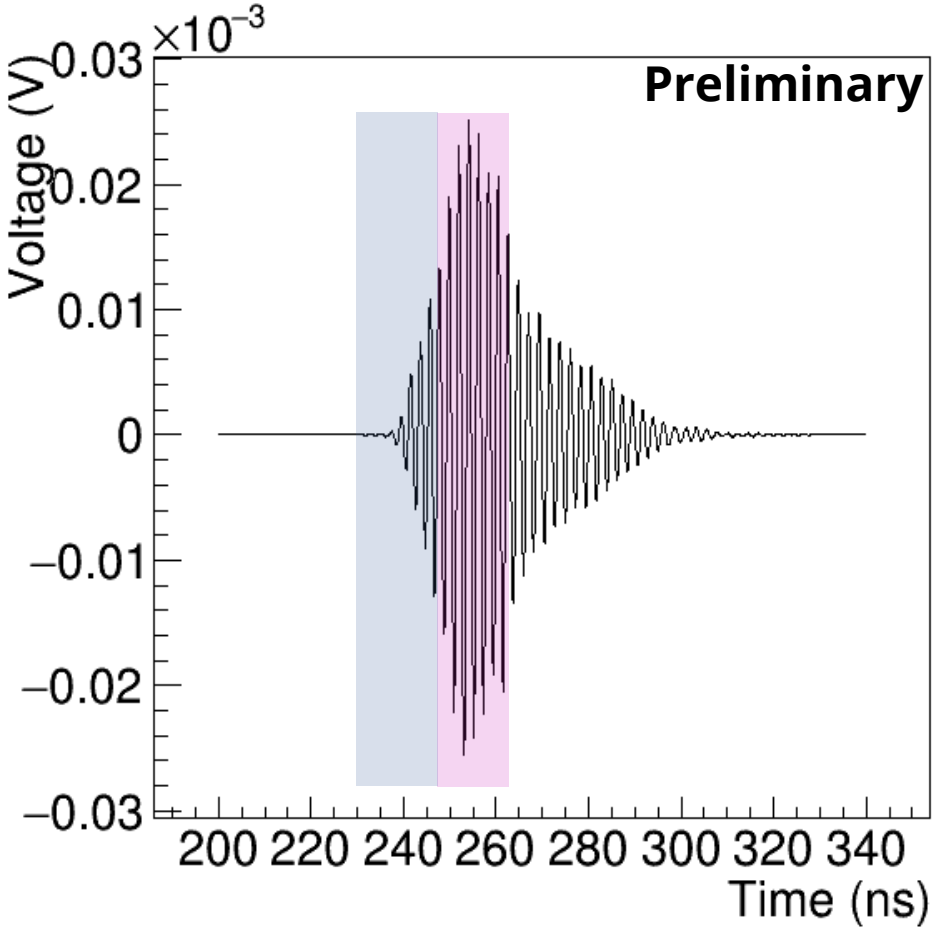


Transmit frequency (450 MHz)

- Three phases of a RET event:
  - Cascade development

Investigation of Received Signal Properties

- RET simulated using RadioScatter (in-house radar reflection simulation with GEANT4) arXiv:1710.02883

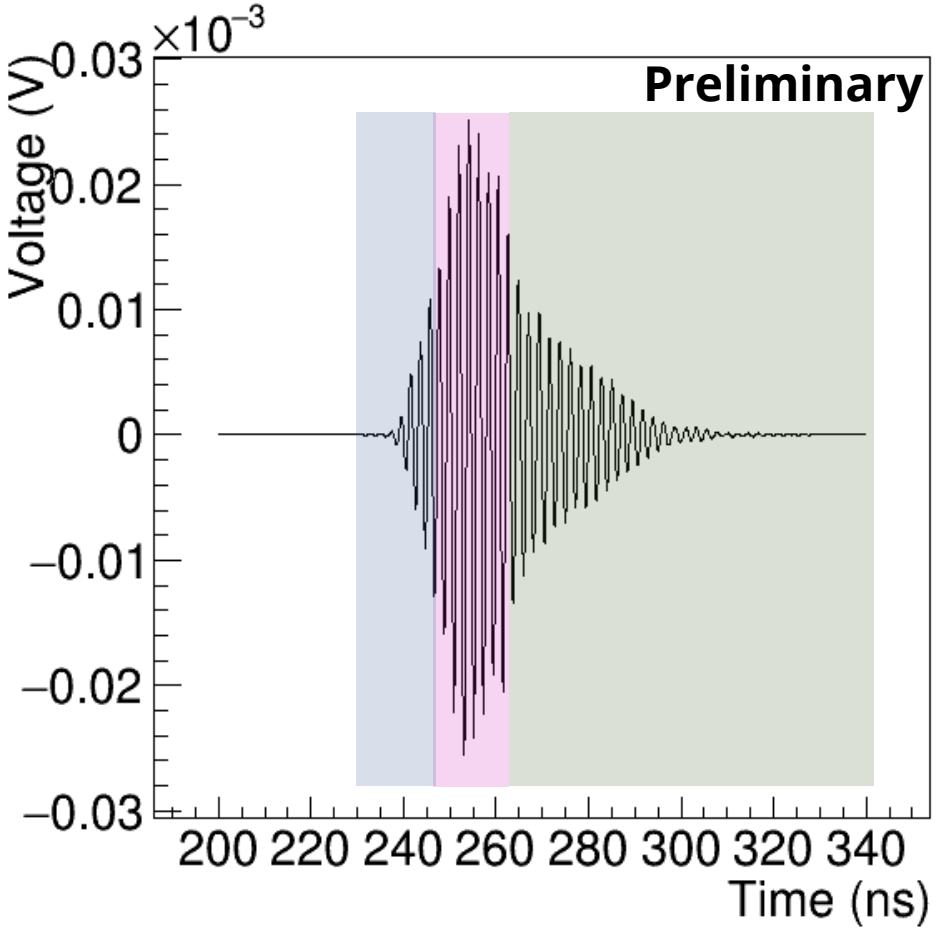


Transmit frequency (450 MHz)

- Three phases of a RET event:
  - Cascade development
  - Cascade as a static reflector

Investigation of Received Signal Properties

- RET simulated using RadioScatter (in-house radar reflection simulation with GEANT4) arXiv:1710.02883

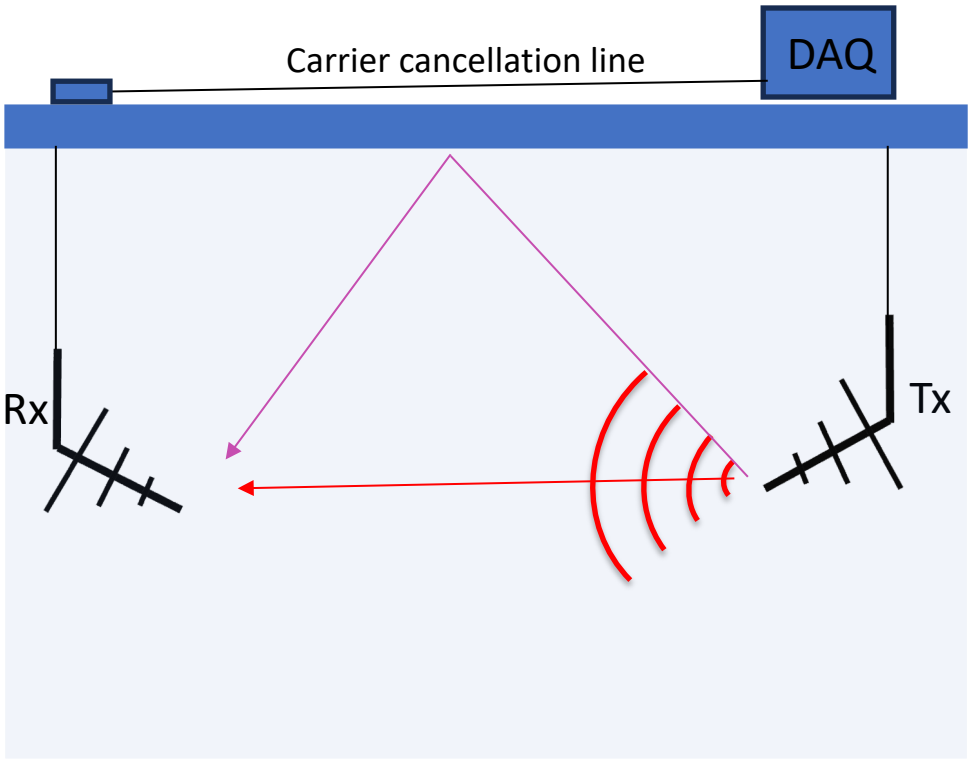


- Three phases of a RET event:
  - Cascade development
  - Cascade as a static reflector
  - Recombination/Attachment

Transmit frequency (450 MHz)

RET-CR Transmitter Cancellation

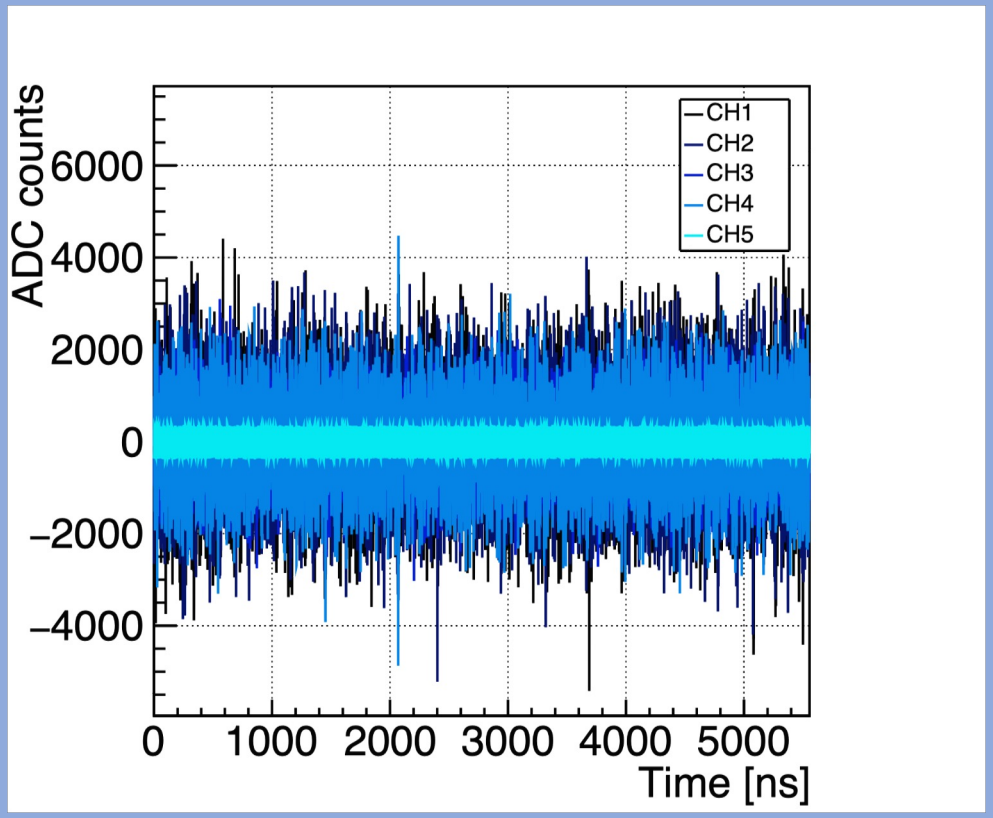
- Problem: high power transmitter close to receivers will saturate amplifiers
- Solution: cancel the direct and reflected transmit signal out of the receiver path
- Cancellation signal is input to Rx line before amplification

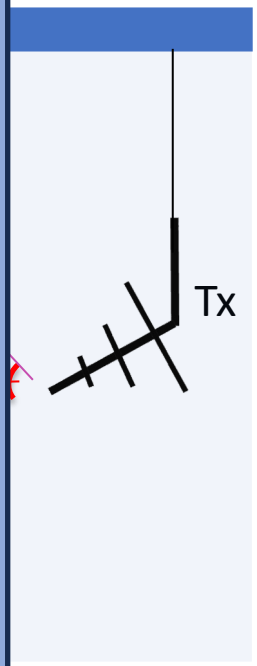


RET-CR Transmitter Cancellation

- Proble
  satura
- Soluti
  reflec
  the re
  - Car
    line

Results: Thermal Noise!





RET-CR Initial Performance

- Second stage of transmitter signal cancellation routine shows a ~60 dBm/Hz reduction of received power
- Prevents saturation of receiver antennas while allowing signal through uncancelled